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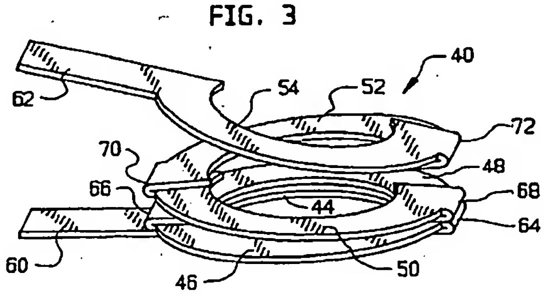
(54) A helical induction coil, a device for forming and a method of making same.

(57) A helical induction coil (40) for high frequency, high power transformer connection purposes, a device for forming such coil (40) from a blank as well as a method of making such coil (40) are disclosed. The coil (40) is formed by cutting partial coil turns (44 - 54), attached to each other at fold lines (64 - 72), from a metal sheet. The width to thickness has a ratio greater than 10 : 1. After cutting, the blank is folded so that the partial coil turns (44 - 54) partially overlie each other to form a helix wherein each of the helix portions are attached to each other by means of a fold (64 - 72) in the parent metal. The helix is preferably a circular coil (40) when completed (Fig. 3).

FIG. 3



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This invention is directed to a helical induction coil comprising a predetermined number of turns, the turns being made of bendable metal having a width-to-thickness ratio of greater than 10 : 1, the turns respectively overlying each other to form the helical induction coil.

This invention, further, is directed to a device for forming a helical induction coil having turns with a width greater than ten times its thickness.

This invention, moreover, is directed to a method of making a helical induction coil with turns having a width-to-thickness ratio of greater than 10 : 1.

High frequency electrical conductors carry the principle current near the surface and, in equipment where small size is mandated, thin conductors are required. In addition, high current requires adequate conductive area near the skin. This results in helical coils in an induction structure which have a ratio of width-to-thickness much greater than 10 : 1. A thin but wide helical conductor is required to handle high frequency and high current. High frequency requires conductor thickness to be as little as 0,006 Inch (0,1524 mm) to eliminate unneeded material due to the skin effect. The requirement for high current forces the conductor width to be much greater than ten times the thickness. There have been several different manufacturing processes which have attempted to fabricate helical induction coils. Machining the coils from the solid can yield coil thicknesses no less than 0,020 Inch (0,508 mm) thick, and the labor involved in machining such structures is extremely high. Metal-forming processes for such coils use conical rollers to shape the metal into helical conductors. However, any looseness within the rolling machine will cause the helical coil to vary in diameter and thickness. An aspect ratio (width-to-thickness) greater than 10 : 1 causes the metal being rolled to thin out on the outside diameter or wrinkle at the inside diameter of the helix. The rolling process requires constant machine adjustment which, in turn, requires a substantial amount of skilled labor. Furthermore, the constant machine adjustment provides a great variability in the product from coil to coil, thus making the assembly cost very high. Another way of fabricating a helical induction coil of high aspect ratio is to cut out some circular strips of conductor and solder them together to form the helix. This manner of construction is also extremely labor-intensive.

It is, therefore, an object of this invention to further improve the coil, the device and the method, mentioned at the outset in order to make production of helical induction coils with flat conductors much simpler and less expensive.

According to the coil specified at the outset, this object is achieved by:

- a first partial turn;
- a second partial turn attached to the first partial turn at a first fold;
- a third partial turn attached to the second partial turn at a second fold; and
- a last partial turn attached to the coil with a last fold.

Moreover, the object is achieved according to the device specified at the outset by a blank comprising a plurality of partial turns each lying in the same plane and each being formed in the same sheet of sheet metal, each of the partial turns being attached to the adjacent partial turn on a fold line, the fold lines being positioned so that when the blank is folded on the fold lines the partial turns partially overlap each other to form the helical coil.

Finally, the object is achieved according to the method specified at the outset with the following steps:

- cutting from sheet metal a plurality of partial coil turns attached to each other along fold lines; and
- folding the partial coil turns with respect to each other so that the partial coil turns partly overlie each other.

The object underlying the invention is thus fully achieved.

Further preferred embodiments of the invention are defined in the appended dependent claims.

In order to aid in the understanding of this invention, it can be stated in essentially summary form that it is directed to a helical induction coil and the method for making the coil. The coil starts as a thin sheet of conductor. It is stamped or otherwise cut to form a plurality or arcuate coil segments which are joined to each other on a fold line which is at a right angle to a line from the center of the coil. When the sheet is folded at the fold line, a coil is formed. The arcuate coil sections can be greater or less than 180 degrees. The coil overlaps the fold and is joined at the fold with parent material.

It is, thus, a purpose and advantage of this invention to provide a helical induction coil which has an aspect ratio much higher than 10 : 1 so that high current and high frequency can be achieved in an induction coil of limited size.

It is a further purpose and advantage of this invention to provide a helical induction coil formed of arcuate segments which are joined together at fold lines of the parent material so that a plurality of arcuate sections can form a several turn coil.

It is another purpose and advantage of this invention to provide a method for making a high aspect ratio coil including cutting arcuate coil segments from a thin sheet of electrically conductive material while maintaining the segments joined along fold lines, followed by folding the coil segments together to form a complete circular coil.

Other purposes and advantages of this invention will become apparent from a study of the following portion of the specification, the claims and the at-

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tached drawings, wherein:

Fig. 1 is an exploded view of a separable transformer which can utilize the helical induction coil of this invention;

Fig. 2 is a plan view of a first preferred embodiment of a strip of coil segments showing fold lines, as seen after the segments are cut from a sheet of conductor material;

Fig. 3 is a perspective view showing the coil of Fig. 2 substantially folded;

Fig. 4 is a plan view of a second preferred embodiment of induction coil segments as cut from a sheet of conductive material with the segments joined at fold lines;

Fig. 5 is a perspective view, similar to Fig. 3, showing the blank of Fig. 4 substantially completely folded;

Fig. 6 is a plan view of a third preferred embodiment of induction coil segments as cut from a sheet of conductive material with the segments joined at fold lines; and

Fig. 7 is a perspective view, similar to Fig. 3, showing the blank of Fig. 6 substantially completely folded.

As a particular example of a structure which employs a helical induction coil in accordance with this invention, Fig. 1 illustrates a separable inductive charge coupler 10 which is particularly useful as a structure for supplying power for the charging of a battery in a battery-powered vehicle. There is a modern trend toward electrically-powered automobiles, and these electrically-powered automobiles have rechargeable batteries therein. The power of the batteries is used to propel the automobile and to provide for other power needs thereof. There is need to recharge the batteries periodically so that the automobile may be taken on another excursion. With fairly large battery capacity, there is need to recharge a substantial amount of power.

It is desirable to make a coupling between the charging station and the automobile which does not require the direct transfer of electricity. A magnetic coupling is desirable. The inductive charge coupler is a transformer primary and contains an appropriate magnetic conductor. The inductive charge receptacle slot contains the secondary winding(s) together with the rest of the magnetic core. The transformer secondary in the automobile is connected through appropriate electrical equipment to the battery for the charging thereof. The frequency is preferably much higher than the ordinary power line frequency for advantages coupling permitting smaller coupler size, and high charge rates are above 10 kilowatts.

In vehicles, it is necessary to disconnect the charging source from the battery, but in accordance with this example of the utilization of the helical induction coil of this invention, the charging connection 10 will be inductive. A transformer primary coil is designed to receive power from a power source and to deliver the power through magnetic coupling to a transformer secondary coil in the automobile. The secondary coil is appropriately connected to charge the automobile batteries. The power supply frequency is chosen in connection with the overall power supply parameters, including the transformer parameters. Inductive charge coupler 12 is seen plugged into the inductive charge receptacle 14 of the automobile in Fig. 1. The coupler 12 is connected to the fixed power source by means of cable 16. The cable 16, seen in Fig. 1, incorporates the electrical cable, coolant tubes (if necessary), and control signal circuitry. As seen in Fig. 1, inductive charge coupler 12 has a handle 18 by which it can be manually manipulated.

The coupler 12 has a panel 20 mounted on the handle 18 so it is manipulated by the handle 18. Panel 20 is supported by a non-magnetic structure extending down from the handle 18, and the panel 20 has a primary winding 22 thereon and a first magnetic core 24 which serves as part of the magnetic circuit. This inductive charge coupler 12 is the unit which is manipulated by the handle 18 and serves as a transformer primary.

The inductive charge receptacle 14 is compatible and physically receives the coupler 12 and magnetically couples therewith. The receptacle 14 has a slot (shown schematically) being sized to receive the panel 20 on the coupler 12. It has, further, two secondary windings 30, 32, and has the magnetic structure to complete the magnetic circuit. Starting from the left end of the receptacle 14, as seen in Fig. 1, first magnetic cap 26 has a second core 28 which lies against first core 24. First secondary winding 30 lies around second core 28 and against one lateral side of primary winding 22. Second secondary winding 32 lies against the opposite lateral side of primary winding 22 and around a third core (not shown) of second magnetic cap 34. The magnetic circuit is completed around the sides of the coils 22, 30, 32 by means of four fingers on each of the caps 26, 34 which are in direct contact and engagement. For example, finger 36 on first cap 26 is in direct contact with finger 38 on second cap 34.

Receptacle 14 is illustrated as having built-in cooling. There are coolant channels in a first cooling ring 37 and coolant channels in a second cooling ring 39, as seen in Fig. 1. Coolant fluid is supplied, as required to limit temperatures.

The primary winding 22 and the secondary windings 30 and 32 are high frequency and high power windings. To achieve efficiency, the windings 22, 30, 32 should be flat but wide coils, as discussed above. Figs. 2, 4 and 6 illustrate blanks from which suitable windings can be made.

While circular coils are specifically disclosed, it is clear that the induction coil could be made with other than circular windings. For example, square, oval or

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rectangular windings are possible for particular coil configurations. The circular coil is most efficient at higher frequencies and thus is disclosed as the preferred embodiment. However, within the term "coil", other than circular configurations are also included.

Figs. 2 and 3 show winding 40, respectively in a configuration as a blank 42 and in the configuration where the blank 42 is almost completely folded into the winding 40. Blank 42 is formed of a group of partial circles which are joined together along fold lines. Partial circles 44, 46, 48, 50, 52 and 54 are illustrated in Fig. 2. Partial circles 44 and 54, respectively, have leads 60 and 62 thereon. These arcuate segments are referred to as partial circles 44 - 54 or as semi-circles, even though in other embodiments including rectangles and squares, they may not subtend 180 degrees. In that sense, the word "semi-circle" is used to indicate a part of a circle rather than half of one. Of course, in Fig. 2, the partial circles 44 - 54 are substantially half circles which extend beyond the half circle subtended arc to permit overlap of the half circles 44 - 54 at fold lines. Fold lines 64, 66, 68, 70, and 72 are shown in Fig. 2. The subtended arc or amount of the partial circle 44 -54 is the radius to the fold line 64 - 72. In other words, the fold line 64 - 72 is a line at right angles to the design radius of the partial circle 44 - 54. In Fig. 2, the design arc of one-half turn, and th radius lines perpendicular to the fold lines 64 - 72 are at 180 degrees to each other.

The blank 42 is formed by any convenient means, such as cutting it out of a sheet of electrically conductive metal. It may be electrical copper of a thickness of 0,006 Inch (0,1524 mm). The radial width of each of the partial circular arcs may be 0,500 Inch (12,7 mm) to thus produce a width-to-thickness aspect ratio much greater than 10 : 1. The blank 42 may be cut from the sheet by stamping, die cutting, laser cutting, or other appropriate technique. After the blank 42 is fabricated, the coil 40 is formed by bending the blank 42 on its fold lines 64 - 72 so that the partial circles 44 - 54 subsequently overlie each other to form a helical coil. In Fig. 3, the coil winding 40 is partially unfolded to show the various partial circles 44 - 54 which contribute to the complete winding 40. Lead 60 lies adjacent lead 62 in Fig. 3, but if it was more convenient for connection, the leads 60, 62 could be a half turn away from each other. It is seen that each partial circle 44 - 54 or semi-circle has a subtended arc from the center of the circle to the center of opposite fold lines 64 - 72. In the case of Fig. 2, this arc is 180 degrees. As will be disclosed with respect to Figs. 4 - 7, the arc may be different than 180 degrees.

The number of semi-circles and the location of the folds are predetermined by the following formula:

$d = (n/A)\ 360,$

wherein:

d = the number of angular degrees in the partial circle;

n = number of turns required in the helical coil; and

A = the number of partial turns required (should be an integer)

preferably

$A = 360/i$ (pick i so A is as small as possible); with

i = any integer.

To prevent the semi-circles from intersecting, n/A must be less than 0,83.

If the connections leads 60, 62 are to extend from the same side of the coil 40, then

$dA/360$ = integer.

Employing this formula with respect to the coil winding 40, as shown in Fig. 3:

$180 = (3/6)\ 360.$

Fig. 4 shows a blank 74 being cut from a sheet of winding metal such as sheet copper. The blank 74 has semi-circles 76, 78, 80 and 82, respectively joined by fold lines 84, 86 and 88. The semi-circles 76 and 82 respectively carry leads 90 and 92 for external connection. The fold lines are perpendicular to circle radiuses which are 270 degrees apart. Additionally, the radius in partial circle 76, which extends through the center of lead 90, is at 270 degrees from the radius which is at right angles to fold line 84. This relationship also applies to the positioning of the fold line 88 in lead 92. When blank 74 is folded, it also makes a 3-turn coil winding 94, seen in Fig. 5. In Fig. 5, the coil winding 94 is slightly open to show the fold layers. Normally, the layers would lie against each other. The parts of the winding identified in Fig. 4 are also seen in Fig. 5. With respect to the winding 94, d = 270 degrees, and the coil 94 is a 3-turn coil the same as the one illustrated in Fig. 3. Thus, utilization the formula:

$270 = (3/4)\ 360.$

The advantage of the helix in Fig. 5 over that shown in Fig. 3 is that the folds do not lie on top of each other, thus reducing the thickness increase due to the fold.

Fig. 6 shows a blank 96 from which is folded a 20-turn coil winding 98, shown in Fig. 7. In this case:

d = 300

n = 10 and

A = 10/12.

In this case, blank material is conserved by positioning the semi-circles of the blank adjacent each other, as seen in Fig. 6. In view of the large number of partial circles to form the coil winding 98, only the semi-circles adjacent the ends will be specifically identified. Lead 100 is integrally formed radially on the end of the semi-circle 102, which is joined to semi-circle 104 at fold line 106. The lead is connected with its center line on a radius, and the fold line 106 is at a right angle to the radius of both semi-circles 102 and 104. These semi-circles continue, joined by fold lines which are at a right angle to the radius through the center of the fold line. The last two semi-circles 108

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and 110 are joined at fold line 112. Connector lead 114 is attached to semi-circle 110 on the radius, as previously described. There is a large number of different helical windings which can be produced within the bounds of the above formula by different values of d and A.

As in conventional coil winding practice, the conductor is supplied with an insulating layer before being folded into helical configuration. This provides insulation between the successive windings. Testing of these folded helical coils indicates that the performance is similar to helical coils made by the rolling process or by the cut-and-solder process.

Claims

1. A helical induction coil comprising a predetermined number of turns, said turns being made of bendable metal having a width-to-thickness ratio of greater than 10 : 1, said turns respectively overlying each other to form said helical induction coil (22, 30, 32; 40; 94; 98), characterized by:
   - a first partial turn (44; 76; 102);
   - a second partial turn (46; 78; 104) being attached to said first partial turn (44; 76; 102) at a first fold (64; 84; 106);
   - a third partial turn (48; 80) being attached to said second partial turn (46; 78; 104) at a second fold (66; 86); and
   - a last partial turn (54; 82; 110) being attached to said coil (40; 94; 98) with a last fold (72; 88; 112).

2. The coil of claim 1, characterized in that said first partial turn (44; 76; 102) and said last partial turn (54; 82; 110) have connecting leads (60, 62; 90, 92; 100, 114) thereon so that said coil (40; 94; 98) can be electrically connected.

3. The coil of claim 2, characterized in that said connecting leads (60, 62; 90, 92; 100, 114) are parallel to each other.

4. The coil of any of claims 1 - 3, characterized in that said partial turns (44 - 54; 76 - 82; 102, 104, 108, 110) are essentially shaped as partial circles.

5. The coil of claim 4, characterized in that the lines of said folds (64 - 72; 84 - 88; 106, 112) lie at a right angle to that radius of said partial circles directing to the end of said partial circles adjoining said folds (64 - 72; 84 - 88; 106, 112).

6. The coil of claim 4 or 5, characterized in that the number of said partial turns (44 - 54; 76 - 82; 102, 104, 108, 110) is defined by:

   $$d = (n/A)\ 360,$$

   where:

   d = the number of angular degrees in the partial circle;

   n = the number of turns required in the helical coil (40; 94; 98); and

   A = the number of partial turns (44 - 54; 76 - 82; 102, 104, 108, 110) required.

7. The coil of claim 6, characterized by the relationship:

   $$dA/360 = \text{any integer}.$$

8. A device for forming a helical induction coil having turns with a width greater than ten times its thickness, characterized by a blank (42; 74; 96) comprising a plurality of partial turns (44 - 54; 76 - 82; 102, 104, 108, 110) each lying in the same plane and each being formed in the same sheet of sheet metal, each of said partial turns (44 - 54; 76 - 82; 102, 104, 108, 110) being attached to the adjacent partial turn (44 - 54; 76 - 82; 102, 104, 108, 110) on a fold line (64 - 72; 84 - 88; 106, 112), said fold lines (64 - 72; 84 - 88; 106, 112) being positioned so that when said blank (42; 74; 96) is folded on said fold lines (64 - 72; 84 - 88; 106, 112) said partial turns (44 - 54; 76 - 82; 102, 104, 108, 110) partially overlap each other to form said helical coil (40; 94; 98).

9. The blank of claim 8, characterized in that the first (44; 76; 102) and last (54; 82; 110) partial turns attached to said coil (40; 94; 98) along fold lines (64, 72; 84, 88; 106, 112) each have a connection lead (60, 62; 90, 92; 100, 114) integrally formed thereon.

10. The blank of claim 8 or 9, characterized in that said connecting leads (60, 62; 90, 92; 100, 114) are parallel to each other.

11. The blank of any of claims 8 - 10, characterized in that said partial turns (44 - 54; 76 - 82; 102, 104, 108, 110) are essentially shaped as partial circles.

12. The blank of claim 11, characterized in that the lines of said folds (64 - 72; 84 - 88; 106, 112) lie at a right angle to that radius of said partial circles directed to the end of said partial circles adjoining said folds (64 - 72; 84 - 88; 106, 112).

13. The blank of claim 11 or 12, characterized in that the number of said partial turns (44 - 54, 76 - 82; 102, 104, 108, 110) is defined by:

    $$d = (n/A)\ 360,$$

    where:

    d = the number of angular degrees

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in the partial circle;

n = the number of turns required in the helical coil (40; 94; 98); and

A = the number of partial turns (44 - 54; 76 - 82; 102, 104, 108, 110) required.

14. A method of making a helical induction coil with turns having a width-to-thickness ratio greater than 10 : 1, characterized by the steps of:
   - cutting from sheet metal a plurality of partial coil turns (44 - 54; 76 - 82; 102, 104, 108, 110) attached to each other along fold lines (64 - 72; 84 - 88; 106, 112); and
   - folding the partial coil turns (44 - 54; 76 - 82; 102, 104, 108, 110) with respect to each other so that the partial coil turns (44 - 54; 76 - 82; 102, 104, 108, 110) partly overlie each other.

15. The method of claim 14, characterized in that the cutting step in part comprises cutting the partial coil turns (44 - 54; 76 - 82; 102, 104, 108, 110) essentially along partial circles and defining the fold lines (64 - 72; 84 - 88; 106, 112) therebetween at a right angle to that radius of said partial circles directed to the end of said partial circles adjoining said folds (64 - 72; 84, 88; 106, 112).

16. The method of claim 15, characterized in that the cutting step includes cutting the partial coil turns (44 - 54; 76 - 82; 102, 104, 108, 110) in accordance with the following:

$$d = (n/A)\ 360,$$

where:

d = the number of angular degrees in the partial circle;

n = the number of turns required in the helical coil (40; 94; 98); and

A = the number of partial turns (44 - 54; 76 - 82; 102, 104, 108, 110) required.

17. The method of claim 16, characterized in that a connecting lead (60, 62; 90, 92; 100, 114) is integrally formed on each of the end partial coils (44, 54; 76, 82; 102, 110) and positioned so that when folded said connecting leads (60, 62; 90, 92; 100, 114) are parallel to each other.

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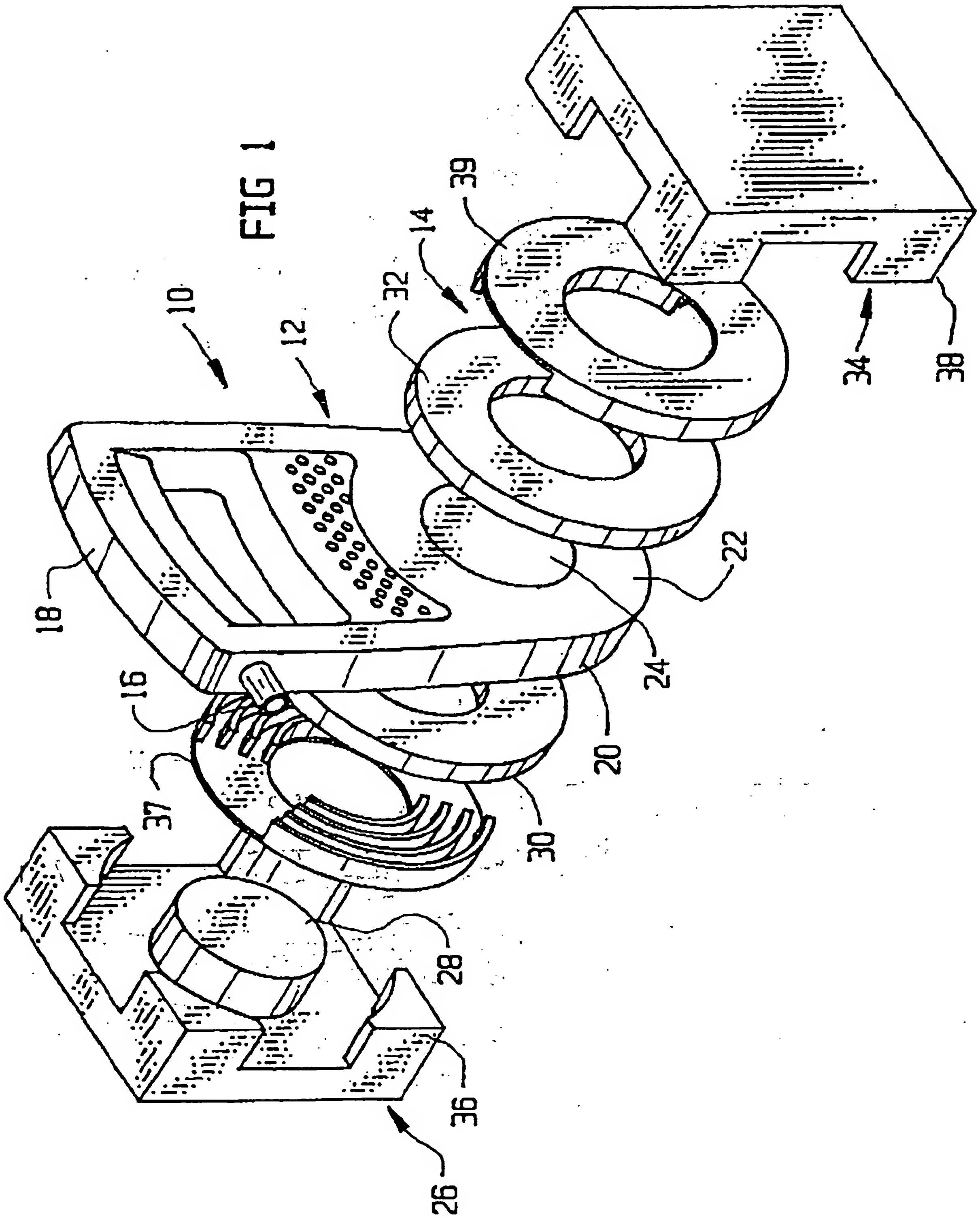

FIG 1

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FIG. 2

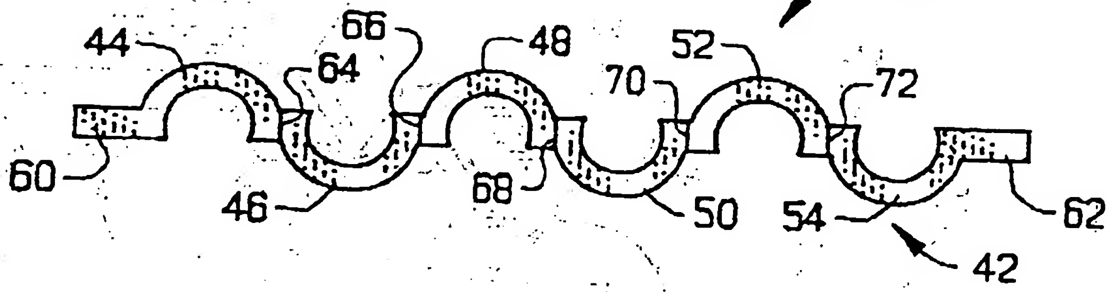

FIG. 3

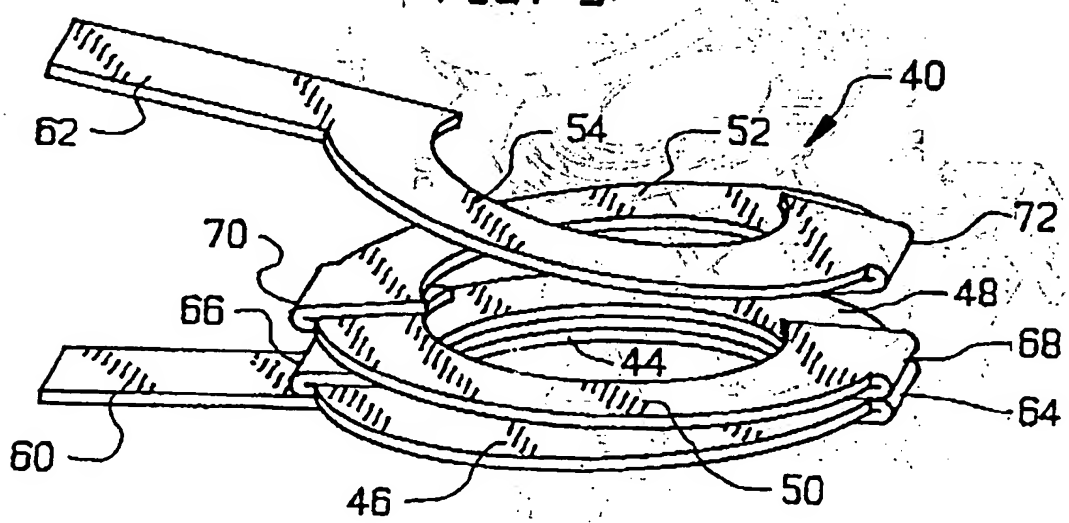

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FIG. 4

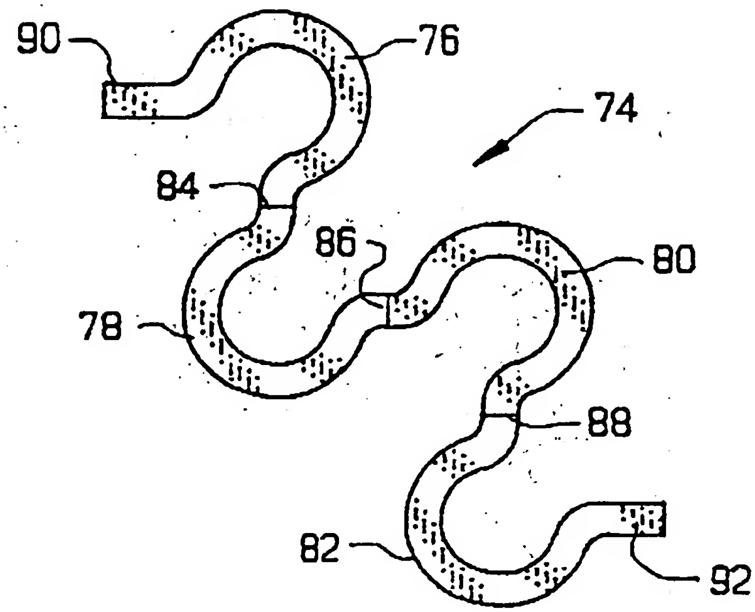

FIG. 5

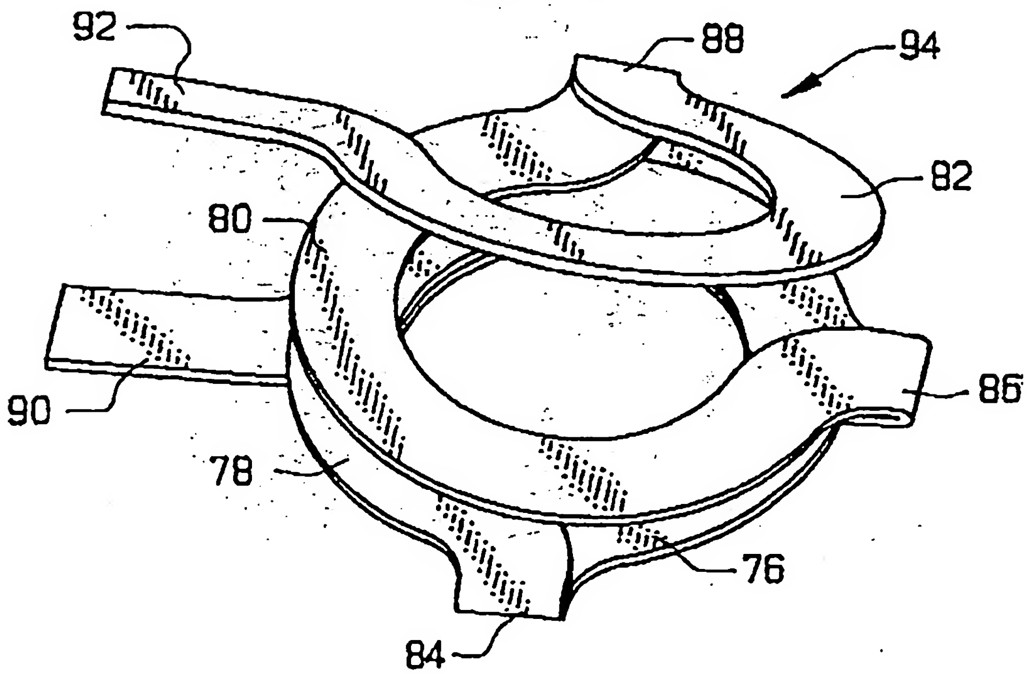

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FIG. 6

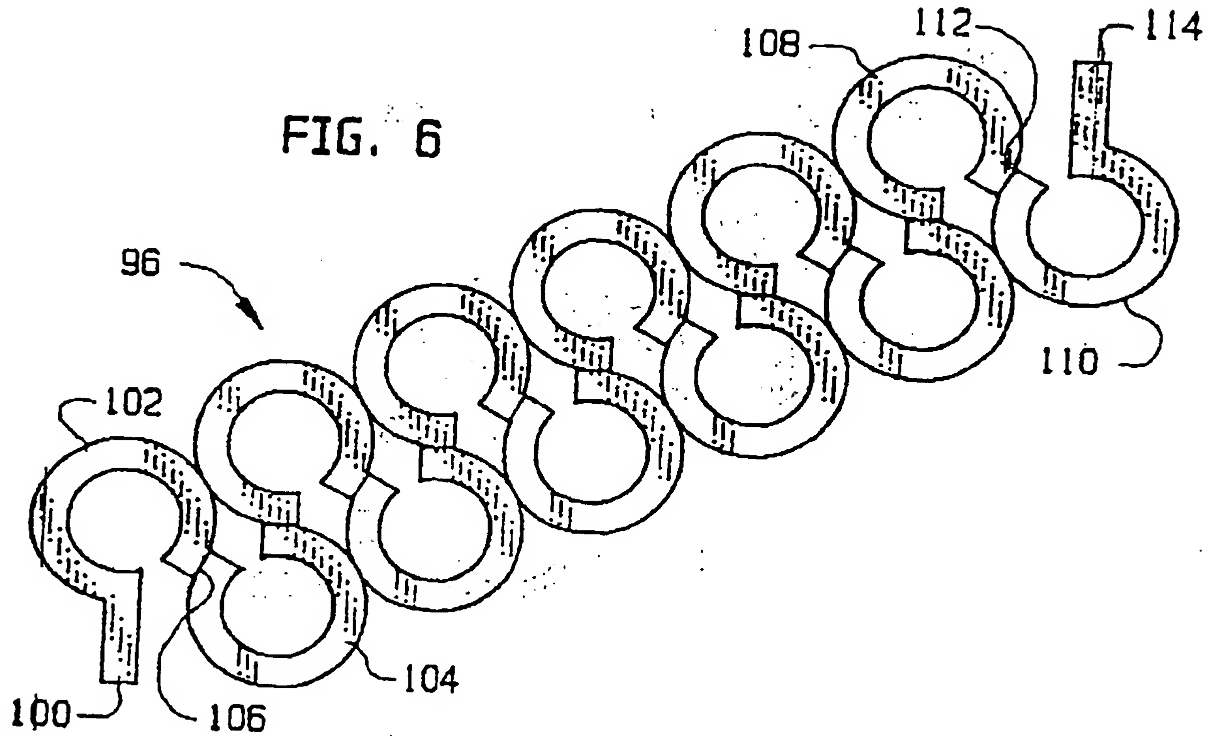
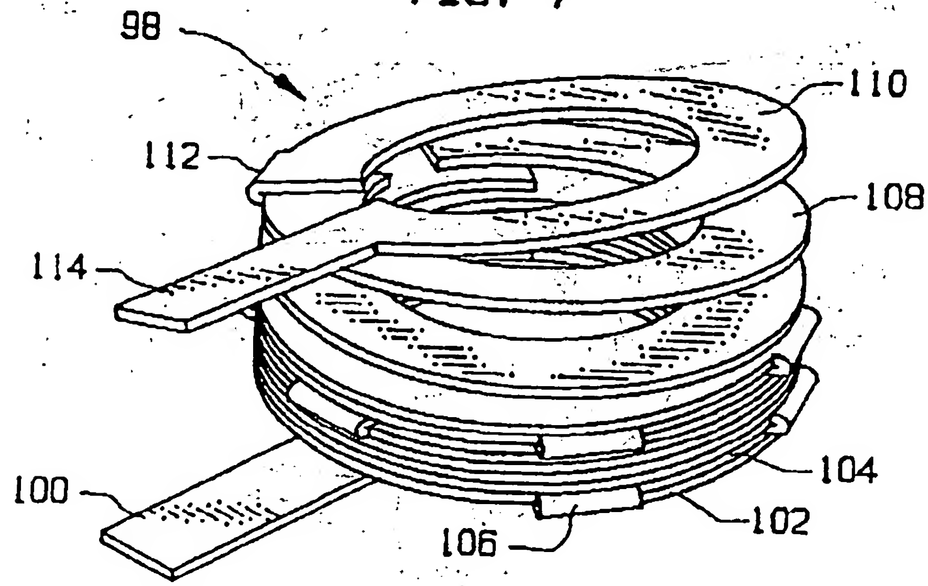


FIG. 7



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European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 10 0242

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	PATENT ABSTRACTS OF JAPAN vol. 008 no. 107 (E-245) ,19 May 1984 & JP-A-59 023510 (HITACHI SEISAKUSHO KK) 7 February 1984, * abstract *	1-17	H01F41/04 H01F27/28
A	DE-A-36 43 044 (BYSTRICAN IVAN) 30 June 1988		
A	GB-A-N29274 (J.W.EWART) & GB--29274 A.D. 1913		
A	DE-C-148 789 (HARTMANN & BRAUN)		
A	PATENT ABSTRACTS OF JAPAN vol. 011 no. 007 (E-469) ,9 January 1987 & JP-A-61 184806 (TOKYO KOSUMOSU DENKI KK) 18 August 1986, * abstract *		
A	PATENT ABSTRACTS OF JAPAN vol. 004 no. 189 (E-039) ,25 December 1980 & JP-A-55 132007 (MATSUSHITA ELECTRIC WORKS LTD) 14 October 1980, * abstract *		TECHNICAL FIELDS SEARCHED (Int.Cl.6) H01F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	11 April 1995	Vanhulle, R

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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